

# **Coastal and Near Surface Mixing**

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## **LONG-TERM GOAL**

My long-term goal is to contribute to our understanding of turbulence and mixing processes in the ocean, and to establish how mixing affects the distribution and transport of heat, salt, and other important physical processes.

## **OBJECTIVES**

I wish to establish how the efficiency and the rate of mixing depend upon the shear in currents, the stratification of the density, and the intensity of turbulence. Mixing increases the potential energy of the ocean by raising denser water towards the surface. The efficiency of mixing is the fraction of kinetic energy that is converted to potential energy. The challenge is to measure the mixing directly without relying on models and assumptions about the nature of turbulence.

Sound is backscattered from turbulence and plankton. I want to relate the intensity of turbulence to the backscattering cross-section through the simultaneous measurement of both in the ocean, and to determine the features of the back-scatter that distinguish turbulence from plankton.

## **APPROACH**

We are using a towed vehicle to survey the turbulence in deep tidal channels where, over the course of a tidal cycle, currents, stratification and the intensity of turbulence vary considerably. The towed vehicle (Fig. 1) carries high-resolution velocity and temperature sensors (shear probes and thermistors), current meters, a vertical array of three pairs of salinity and temperature sensors, and motion sensors. These sensors provide a measure of the density stratification, the rate of dissipation of turbulent kinetic energy, and the fluctuations of vertical velocity, salinity and temperature due to turbulent eddies. Simultaneously, we measure the vertical gradient of current using a ship-mounted acoustic current sensor (ADCP), and take profiles of salinity, temperature and density over the full water column using a CTD lowered from the tow-ship. The correlation of the fluctuations of vertical velocity with temperature and salinity provides a direct estimate of the vertical flux of density (hence the rate of mixing) without making any assumptions about the nature of turbulence. The ratio of this flux to the rate of dissipation of kinetic energy gives the efficiency of mixing.

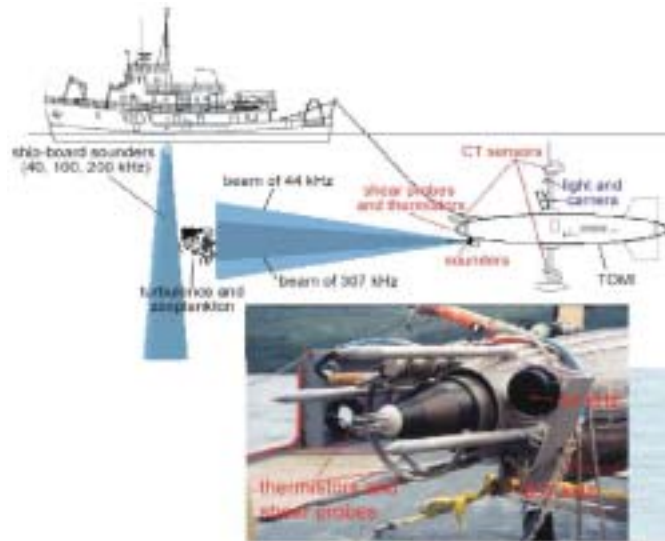


**Fig. 1. The towed vehicle TOMI used for the studies in Sansum Narrows and Knight Inlet. Details of the acoustic transducers are shown in Fig. 2. Four of the six microstructure probes on the nose of the instrument measure velocity fluctuations (shear probes, P1-4) and the other two measure temperature fluctuations (FP07 thermistors, T1-2). One set of the three SeaBird conductivity (salinity) and temperature sensors is mounted close to the shear probes to determine the covariance of vertical velocity with salinity and temperature. The vehicle is 4.5 m long, weighs 4500 N (5 newtons equals 1 pound)) in air, and has an enclosed mass of 800 kg when submerged. Its underwater weight is only 150 N.**

We have also mounted sounders (44 and 307 kHz) just below the turbulence sensors to project sound pulses forward from the towed vehicle (Fig. 2). These pulses are directed along the tow-path of the vehicle and, thus, we simultaneously measure the acoustic backscatter and the turbulence, and can relate them at all positions along the tow track. Simultaneous, but slightly displaced, measurements of backscatter from vertical sounders on the ship allow us to identify scattering layers and to target our tow path. Periodic vertical net tows are used to identify zooplankton species and their abundance.

## WORK COMPLETED

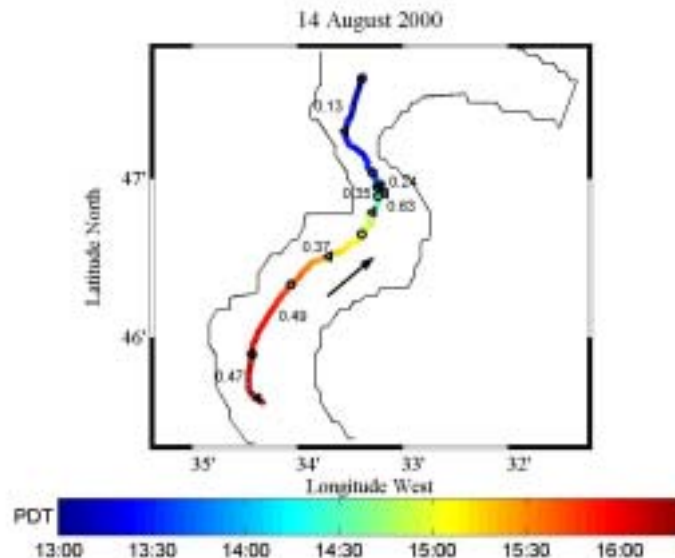
We have completed two cruises to Sansum Narrows (July 1999; August 2000) and collected a total of 80 hours of data which have been used to estimate the vertical fluxes of heat and salt (hence, density). We have completed one cruise around the sill in Knight Inlet (June 2001), known for its internal hydraulic jump, and used these data to examine the relationship between turbulence and backscatter, and to explore the relationship between turbulence and zooplankton distribution.



**Fig. 2.** *The towing arrangement and acoustic insonification during tows over the Knight Inlet sill. The towed vehicle is typically one to two hundred meters behind the tow ship. Inset: close up view of the sounders and turbulence sensors.*

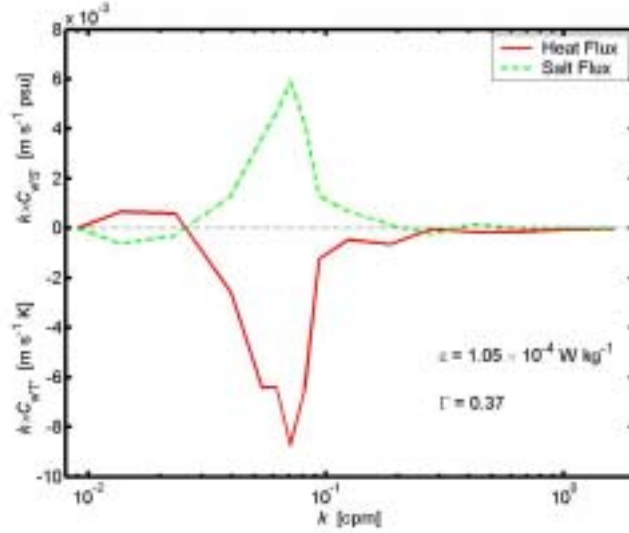
## RESULTS

Figure 3 depicts the mixing efficiency (ratio of density flux to dissipation rate) in Sansum Narrows during a flood tide. The most intense turbulence is in the sharp turn near the north end of the channel but the mixing efficiency there is typically low (0.1 to 0.3). Turbulence is least intense at the southern end (the entrance for a flood) but mixing efficiencies are high.



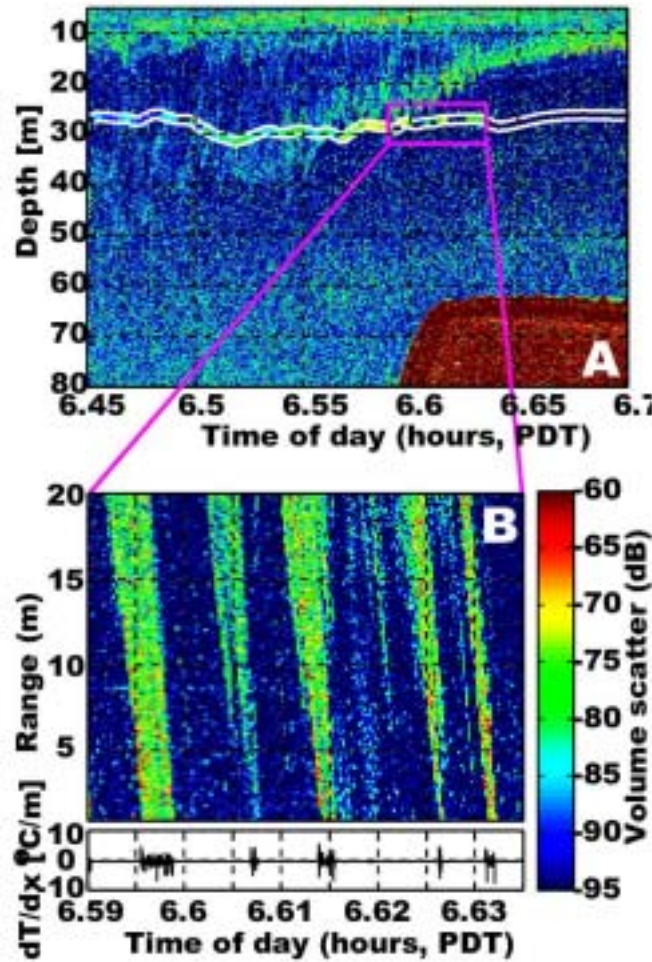
**Fig. 3.** *A typical tow path through Sansum Narrows. The arrow indicates the direction of the flood tide. The numerals indicate the mixing efficiency (ratio of density flux to dissipation rate) and range from 0.13 to 0.47.*

The heat flux is determined from the covariance of vertical velocity fluctuations (measured by the shear probes) and temperature fluctuations (measured with FP07 thermistors), see Fig. 1. The estimates are unchanged if, instead, we use the temperature fluctuations measured by the SBE3F thermometer mounted 0.1 m aft of the shear probes. The salinity flux is estimated from the covariance of vertical velocity and salinity fluctuations (measured with the SBE4 conductivity probe and the SBE3F thermometer). The density (or buoyancy) flux is the sum of the heat and salinity flux after they are scaled by the thermal and saline coefficients of contraction (Fig. 4). The decrease in mixing efficiency with respect to dissipation rate is fairly consistent among all of the tows in Sansum Narrows (both floods and ebbs) but remains high even for buoyancy Reynolds numbers up to  $O(10^6)$ .



**Fig. 4. Co-spectrum of vertical velocity and temperature ( $wT$ ) and vertical velocity and salinity ( $wS$ ) from measurements taken in Sansum Narrows. The water is stably stratified in both salinity and temperature, hence, a positive salt flux and a negative heat flux both indicate transports down gradient. The fluxes are negligible for wavenumbers larger than 0.3 cpm and there is some re-stratification for wavenumbers smaller than 0.02 cpm. The mixing efficiency,  $\Gamma$ , is 37% and the rate of dissipation is  $\varepsilon$ .**

The upper panel of Fig. 5A shows a section of acoustic backscatter derived from sounders mounted on the tow ship as it travels over the edge of the sill in Knight Inlet. The backscatter intensity is color coded from weak to strong by blue to red, respectively. The backscatter makes visible a lee wave that was descending from 15 to 35 m. The pair of white lines depict the path of the tow-vehicle, which crosses through this lee wave. The lower panel in Fig. 5B shows the backscatter as seen by the sounders on the tow-vehicle for a short section of the tow. The horizontal axis is time increasing towards the right while the vertical axis gives the range of echos from ahead of the vehicle. The temperature microstructure gradient, as measured by a turbulence sensor on the nose of the vehicle, is drawn below the sonogram. The turbulence is intermittent or patchy. The turbulence is first detected through the backscatter (when the turbulence is weak at the location of the sensors and acoustic sounders) and is detected by the turbulence sensors when the nose of the vehicle enters into the patches. The vehicle is traveling about 1 m/s, and so, the turbulence is measured by the temperature sensors less than 20 seconds after patches are detected by the sounders.



*Fig. 5. Section of acoustic backscatter over the edge of the sill in Knight Inlet collected with ship-based echo sounders (upper panel, A). The white lines indicate the path of the towed vehicle which was traveling 25 to 30 m below the surface. The lower panel (B) is the backscatter detected with the sounders mounted on the towed vehicle from the time that the vehicle was traveling just below the lee wave over the sill. The lower trace gives the temperature microstructure detected by one sensor on the nose of the vehicle.*

## IMPACT/APPLICATION

Simultaneous measurements of the fluctuations of vertical velocity, salinity and temperature combined with dissipation rates and stratification have never before been made from a single vehicle. Our work demonstrates a new tool for measuring vertical fluxes in the ocean, and shows that the commonly used value of 0.2 for the mixing efficiency must be re-evaluated. Backscatter can be used to detect turbulence and to make quantitative estimates of its strength. Biomass estimates derived from acoustic backscatter may be biased high because this method assumes that all backscatter comes from zooplankton. Our technique also lends itself to the study of the ecologically important issue of the co-occurrence of turbulence and zooplankton.

## TRANSITIONS

The methods and techniques used for the measurement of the heat and salt flux are being transferred to autonomous underwater vehicles (AUVs). See related projects below.

## RELATED PROJECTS

1. Ed Levine of the Naval Undersea Warfare Center and I are using the small autonomous vehicles *REMUS* to study mixing processes in the New Jersey Bight and Massachusetts Bay.
2. Tom Osborn (Johns Hopkins University), Steve Thorpe (South Hampton, UK) and I are using the AUV *Autosub* to examine gravity currents on the continental slope and Langmuir circulation.
3. Manhar Dhanak (Florida Atlantic University) and I are using the *Explorer* AUV to study mixing processes in the Florida Current.
4. Hide Yamazaki (Tokyo University of Fisheries) and I are investigating the breaking of internal-wave near the bottom of the surface mixing layer and the effect of ridges that cross the Kuroshio Current south of Tokyo.

## PUBLICATIONS

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